ADDRESS
"HEAT TREATING
OF STEEL"

BY
FREDERICK J. NEWMAN

NOTE
Stenographically reported. Illustrations reduced from
those shown during the address.

ADDRESS, Delivered by Mr. Frederick J. Newman, President of Chicago Electric Motor Car Co., on the subject of ''HEAT TREATING OF STEEL'', before the Superintendents' and Foremen's Club of the Chicago Branch of the National Metal Trades Association, at the Kuntz-Remmler's Restaurant, Chicago, on Saturday evening, June 17th, 1911.

MR. CHAIRMAN AND GENTLEMEN:

In taking up the subject of the heat treatment of steel, or rather, alloys of iron, we will consider briefly the metallography of iron and steel. By metallography we mean the study of the physical structure, that is, the grains, the crystals —anything that we can see under the microscope. It will not be necessary for us to consider metallurgy or chemistry, but metallography is a necessity.

When we speak of seeing a metal under the microscope, we refer especially to our prepared sample that we are going to examine. We cannot take a fracture and look at it under a high power microscope, because in a fracture we would have high places and low places, and if we looked at it with a glass above 30 magnifications, we would probably have the mountains in focus, but the valleys would not be, so that in order for us to study the structure of steel under the microscope it is necessary for us to take our sample and polish it very highly, so that all the parts are on the same plane. After polishing we etch, that is, we apply a drop of acid and wipe it off quickly. The acid in that way brings out the demarcation line between the grains or crystals, or has different action upon different crystals.

I want to state, however, at the outset, that I am not going to use language, possibly, that is absolutely scientifically correct. I am going to try to tell it to you in a way that a user of steel might be able to understand. I am not going

to try to give it to you in language such as would require a college professor to fathom;—not that you would not understand it, but I am afraid that I probably could not explain it properly, so I will take the responsibility of setting up a substitute which we will call a "mixing theory." Some technical terms will be omitted, principally those which refer to transition structures, so that instead of taking home with you a mixture of technical words you will have a clearer conception of the structure of steel as influenced by heat than you now have.

When we speak of microscopic sections, we refer to a "pin-head size" of a piece of metal. Figure 1 in a photograph under fifty magnifications probably would be as large as a silver dollar, but as you see it here, represented by a linear reproduction, we probably have increased that about eight or ten times in diameter. While we show crystals clearly with a microscope of fifty magnifications, we do not show some of the things that a five hundred diameter microscope would show, but that figure is characteristic of the crystalline formation of all pure metals.

Metals will crystalize in a cubic way or something beyond that, so that as we look at them in a single plane, we will see squares or hexagons.

Each one of these grains is made up of a larger number of smaller grains, but in order to show up a condition of that sort, it requires very much more careful and deeper etching, and at the same time a very much higher power microscope than that from which our figures were taken.

Figure 1 represents, as I said, the condition of pure metal. Now, pure iron is really only a laboratory product. Pure iron is not a commercial product. The nearest that we get to a pure iron is what we know as Norway or Swede's iron. Norway and Swede's iron has been understood or been considered for many years (and the theory is still held by those who do not know) as being a fibrous material, but since the microscope has been used in the study of materials, it has been found that wrought iron is not a fibrous material. If we would look at certain parts of the wrought iron, we would
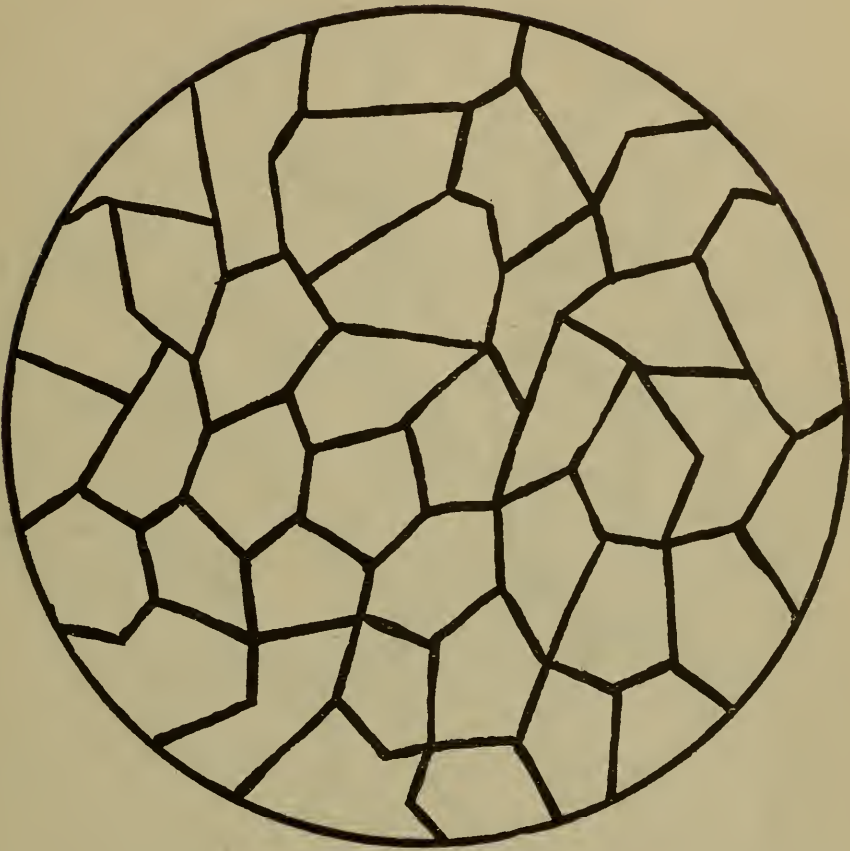
Fig. 1—Pure Metal

find exactly the crystalline structure shown in Figure 1, and then if we looked at other parts of it we would find a condition as shown in Figure 3, and at other parts a condition as shown in Figure 4.

Figure 2 represents a wrought iron bar. Figure 3 is a view taken from the end "A," while Figure 4 is taken from
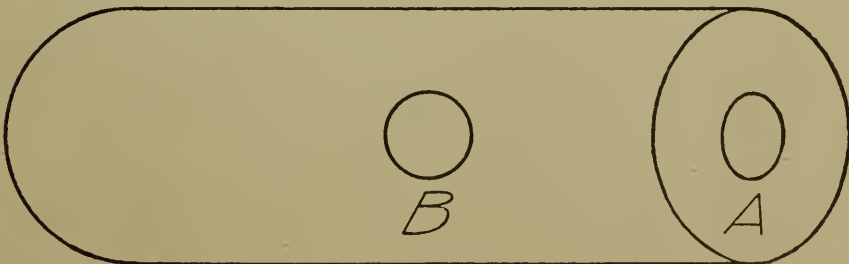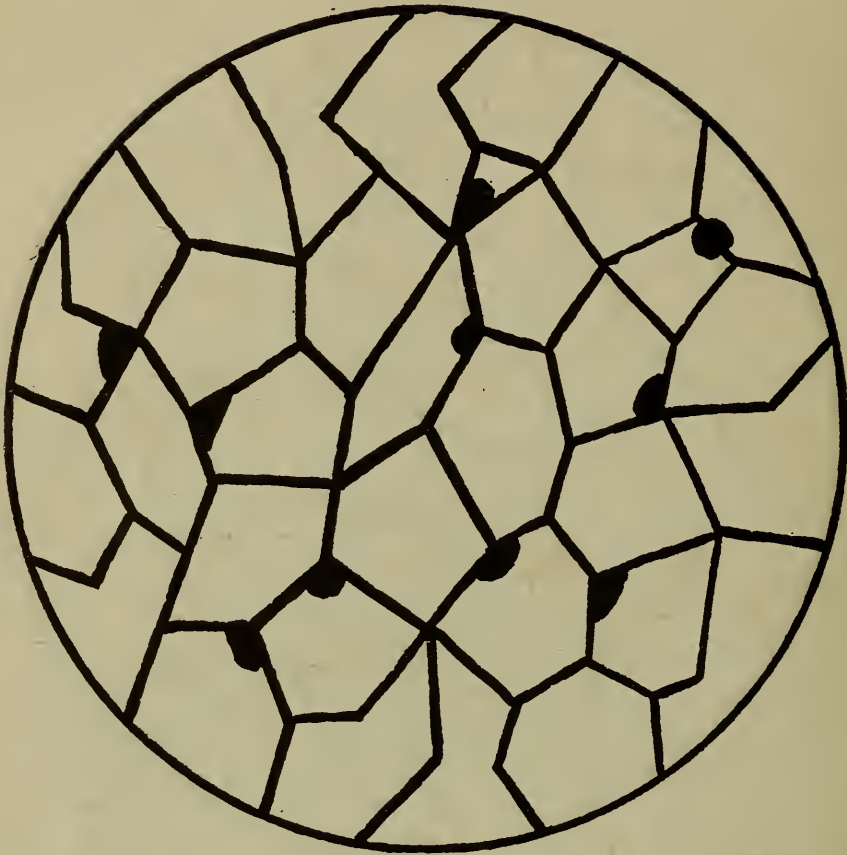

Fig. 2—Wrought Iron

Fig. 3—View A.   Wrought Iron, Showing Slag Between Ferrite Grains

the longitudinal side "B."   Those black specks there are the end views of slag that has been rolled together with the iron. In the other figure the lines represent slag; in other words, the lines and specs are probably the projections of the same pieces, taken in another view.   The slag that is mixed in and rolled out has given us the idea that wrought iron is a fibrous material.   It is not.   It is just as crystalline as any steel can be, but you will probably ask why do we not get it in a brittle condition as we do steel?   I will explain that later on.

Under the microscope sections of wrought iron are just as crystalline as, for instance, screw stock, and the reason that we think it is fibrous is due to the fact (as I have just stated), that slag has been rolled in with it.

These crystals are known as "ferrite."   Ferrite is the carbonless component, or carbonless crystal of iron or steel,

Fig. 4—View B.

and it is that component of iron or steel, or that particular crystal which has the particular property of weldability and ductility; it is also the softest crystal in iron or steel.

Of course, you are all familiar with how wrought iron is made. It is puddled product. If we take iron and melt it and add some carbon and then pour it or cast it, we make steel. There is some carbon in wrought iron, and we can get the same chemical composition, that is, the same amount of iron, carbon and other chemical constituents, such as silicon, phosphorus, manganese, and so forth, in wrought iron as we can in low carbon steel, so that if we take two pieces—that is, one piece of steel and one piece of wrought iron that has exactly the same chemical make-up, the only difference between the two would be the presence of slag in one and the absence in the other, brought about by the melting and subsequent pouring.

I have here a few bolts that have been made of screw stock, which is probably the lowest carbon commercial steel. The first one that we pass is characteristic of the brittle crystalline structure of all carbon steels. The others have been given a heat treatment. One has been nicked and then bent, and the other has not been nicked. I am only showing these now to indicate that the apparent crystalline structure can be removed and that steel can be made to appear just as fibrous as wrought iron.

As we add carbon we get another crystal, or another grain, properly speaking. I speak of these main divisions here as grains, and the finer ones as crystals. That grain is called "Pearlite." Pearlite is that grain which contains the carbon. It is a mixture of an iron carbide (cementite) and some ferrite; in other words, as carbon is added we produce a carbide made up of a chemical union of a little iron and a little carbon, making the chemical formula Fe_3C, and that mixed with a certain amount of the ferrite or carbonless portion gives us the pearlite grain.

We have represented that as dark grain against light colored ferrite grain. Before I continue, however, I might state that in the sections of wrought iron there may be some ferrite, indicating that there was carbon; under a small glass it may be confused with slag; in other words, if there is some carbon in wrought iron, and the chances are there is, that there will be some pearlite. The reason that pearlite appears dark is this:

Under high powers we see it laminated as in Figure 6. In Figure 5 I have shown the ferrite as being light colored, while in Figure 6 the ferrite as being dark colored, and the cementite being light colored. The carbide or cementite is hard. Ferrite is soft. As we polish the tendency is for the fine polishing rouge or polishing powder to polish the soft below the surface of the hard. When we etch, the tendency is for the soft to be below the surface of the hard. We cannot see it with the eye, we cannot detect it with the microscope ordinarily. It takes a trained eye to see it. The light in the microscope shines obliquely on the specimen. It is natural
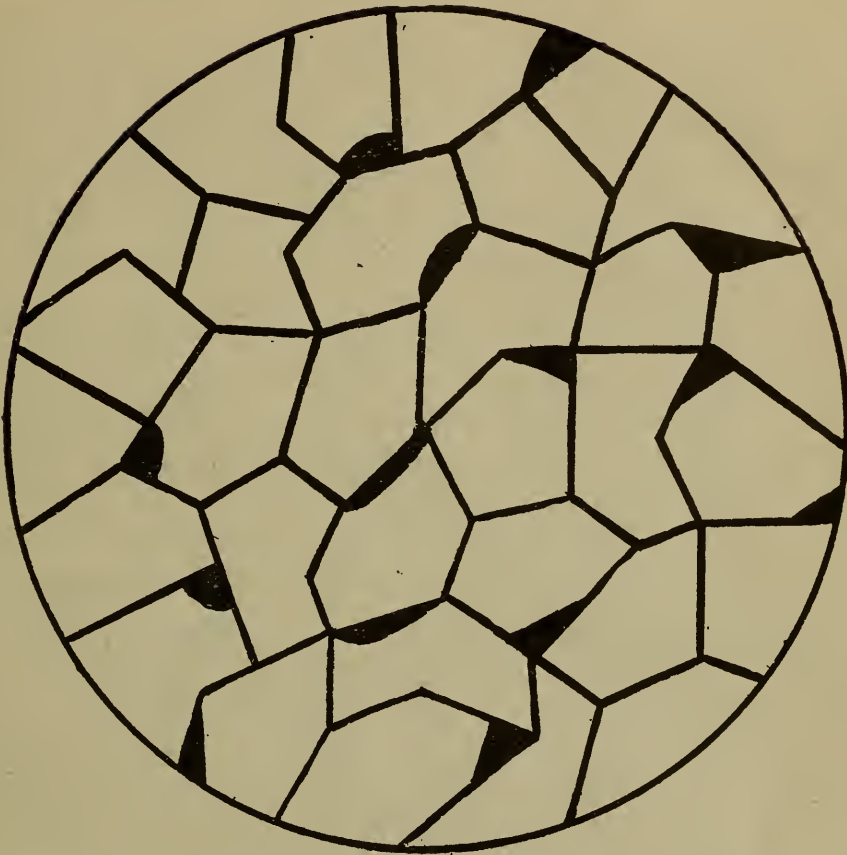
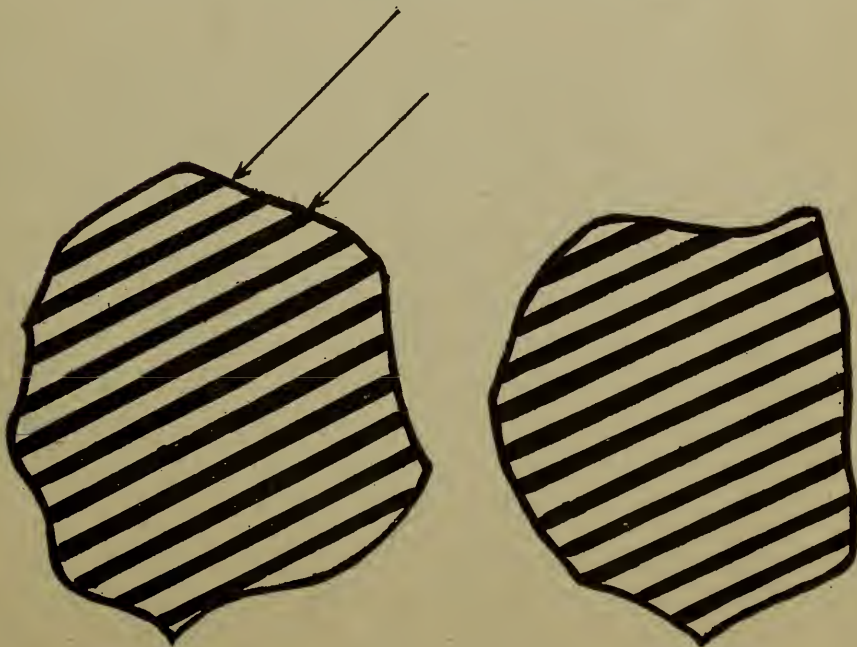Fig. 5— .10 Carbon Steel, Low Magnification

Fig. 6—Pearlite Highly Magnified.

that the high line blocks the light for the low one and puts it in the shadow so that the one that is up high will appear light, that is, it will be the natural color of steel or iron polished, so that when we see, for instance, the light particles in the microscope, the chances are that they are high ones. The low ones are the dark ones, since they are in the shadow of the light ones.

Now, that is the reason why pearlite then, as a whole, will be dark as compared to ferrite, because it has those shadow lines which influence the color of the whole grain. As we add carbon, the ferrite grains decrease and the pearlite grains increase. Figure 5 is characteristic of ten carbon steel, and Figure 7 is characteristic of fifty carbon steel. The increasing carbon gives us more of those dark places until we get up to a condition of eighty or ninety carbon, when we have pearlitic steel, that is, the whole mass becomes pearlite, and then the independent ferrite absolutely disappears.

As we go beyond that, then we begin to get free cementite. There is no free ferrite, because all of the carbide is combined with the iron to make the pearlite, and there is an excess of it, so we get out carbide in a separate and free crystal. For instance, Figure 8 would represent 130 point carbon steel. Here the cementite is white and the pearlite is dark. Again, the cementite as a whole being harder, stands up. If we increase that carbon up to 2 per cent, then we get cast iron. We have a tendency then towards the condition of having nothing but cementite.

As we add carbon we increase the strength up to the condition of all pearlite, up to about 90 points, as we go beyond that, we then get hardness and brittleness due to the carbide; below, softness and ductility. When we get to a condition where there is no more pearlite, it all becomes carbide, then we have the extreme brittleness of cast iron. So we can consider the iron family as follows:

Beginning with wrought iron and low carbon steel, the only difference being in the occluded slag. Next to low carbon steel we have a medium carbon steel, then a high carbon steel, and then we get into cast iron.
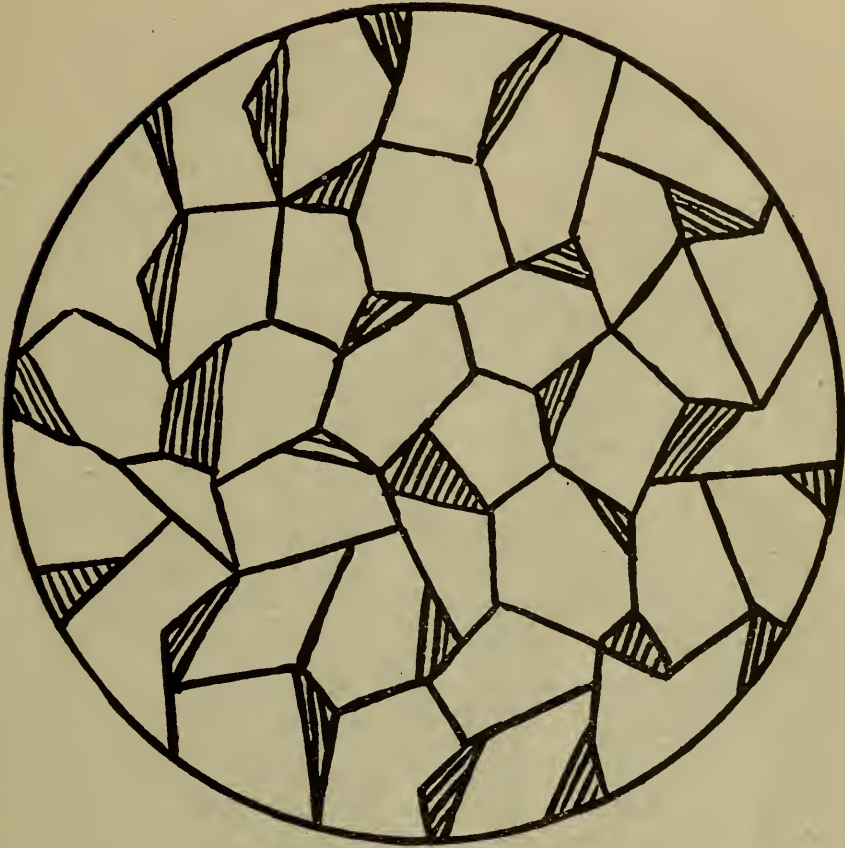
Fig. 7— .50 Carbon Steel

We have three grain conditions that I have spoken of: one is ferrite, that is soft, ductile, and can be welded. We have the carbide condition, which gives us hardness and brittleness. Then we have the pearlite condition, which gives us a combination of both, and when we go so high as to get gray iron, we begin to get a free carbon condition, a condition higher than carbide, and then we get graphite.

In general, I want to state the fact that as we heat to a high temperature, or as we cool from a high temperature, we promote the growth of crystals. The higher the temperature, the larger our crystals. That is a thing that I will want to take up later on in the evening. High temperature promotes the growth of crystals. Slow cooling from high temperatures that is, in pouring castings, also promotes the growth of crystals.
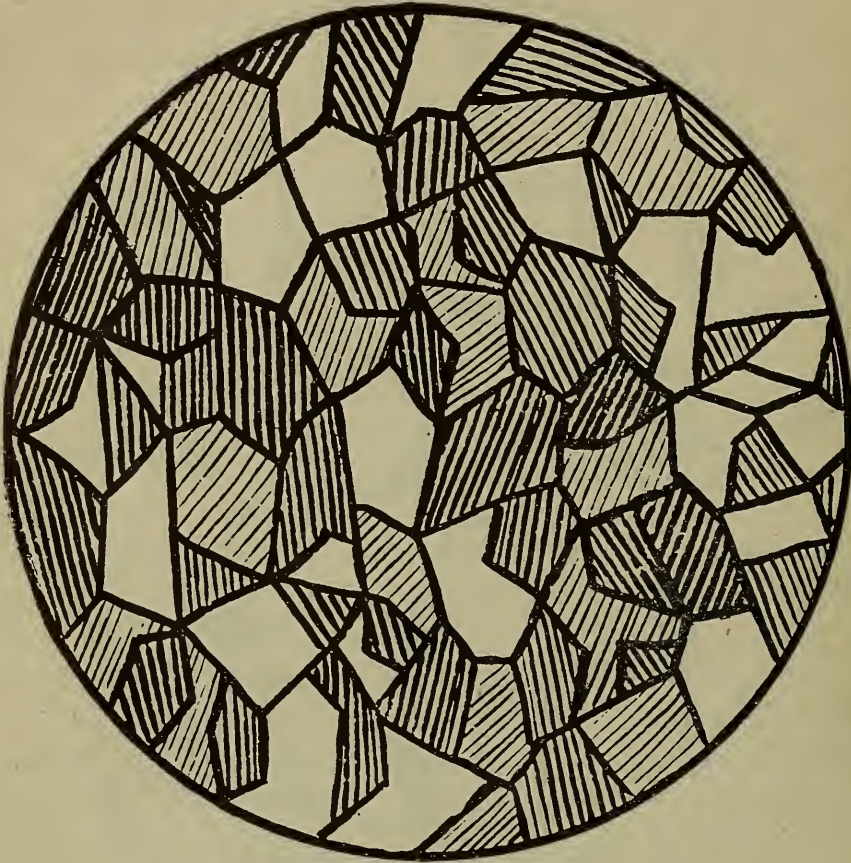
Fig. 8—1.30 Carbon Steel

If we heat a piece of steel, we find this: that the temperature would increase in a continuing amount, until we got to a condition around some of the red points, depending upon the content of the steel—where it refuses to get any hotter momentarily, although we continue to apply heat, and under some specific compositions the temperature will actually drop, although we still apply heat. That is only momentarily, and then the temperature goes up again. If we stop heating after we have reached this point, and allow the piece to cool, we find that the steel will gradually cool until its gets to a certain point, when the reverse takes place. That cooling point that I am speaking of is at a lower temperature than the point that I spoke of in heating. The piece cools until it gets to a certain point, no heat is being applied, but it stops cooling momentarily. In fact in some conditions it gets hotter, and then cools again until we get down to the cold temperature.

I have here a steel wire by which I am going to illustrate that. Before I try the experiment I am going to tell you what is going to happen, so that you will watch for it. We will heat this wire by means of a storage battery which we have connected to it. The expansion or lengthening which takes place due to the heat, of course, will be noted by the sag. As long as that wire sags, it is taking on heat. The instant it stops sagging, although we continue to heat, it is not taking up heat; in fact, if you watch it, you will notice that it will tend to rise a little bit, indicating that it is contracting and cooling, and then an instant after, you will notice that it continues to sag more, indicating it is taking up heat. When we get to that condition I will cut off the power and let it cool down, and you will notice that it is cooling, both by the contraction and change of color until we get to a certain point, and then it will stop, and if you watch for it you will see it sag again, and then it will go up again as it cools. That is what the experiment is going to show, and we will discuss what happens when we get through illustrating.

(At this point Mr. Newman had the room darkened and made the experiment referred to in his preceding remarks.)

I suppose you all noticed that the change occurred and that the change on the cooling side, that is, after I cut off the power, was of a lower redness than on the heating side.

That experiment shows only an outward demonstration of something that has occurred within the steel itself. Several things have occurred within the steel itself. That particular phenomenon is known as recalescence. There are only two things that we are going to consider in our theory as to what has happened. One is the carbon change and the other is the crystal form change.

Truly speaking, there are three points in cooling and heating, but we are only going to consider one in cooling and one in heating. These we will call change points.

Below the change point we have considered our carbon in the form of a carbide, a chemical combination with some iron, the amount depending upon the carbon, and we will know that carbon as "cement carbon." Above the change

point the carbon is in an entirely different condition. It is known as "hardening carbon." Sometimes the carbon there is spoken of as "hardenite."

To change from cement to hardening carbon requires heat. If heat is supplied as fast as it is needed then the temperature momentarily stops rising, but if more heat is required than is supplied, then the temperature actually drops. This takes place in heating.

Now in cooling, the reverse takes place. Heat is liberated in changing from one carbon condition to another and the larger the amount of heat liberated, the clearer is the change point defined. When we mix chemicals together we get heat. In many conditions where we obtain a given chemical change, we either liberate or absorb heat. It is not necessary for us to explain why, but the chemists recognize it, and you all recognize that this condition exists. If a chemical change has taken place, it is reasonable to suppose also that the physical condition or change of the crystals has also taken place.

I must ask you to imagine that when the change point has been passed in heating, that the carbon is dissolved in a matrix of plastic steel and free to float throughout the mass and intimately and uniformly distribute itself in this way. The crystalline formation under this condition is known as "Martensite."

I want to call to your attention that there was a time element in which that change took place. That change was not instantaneous. If it were instantaneous you would not have been able to notice it in the experiment. It took some time for it to change from cement carbon to hardening carbon, and it took some time to change back from hardening carbon to cement carbon. Just on account of that is why we can retain that hardenite carbon condition if we quench it—in other words, if we cool it quicker than the time required for the change to take place. Then we hold in the cool material the crystal that we had in the hot material. That is, we get cold martensite. That, I believe, is plain to understand, so that the rationale now for the hardening condition will be

this: That you must quench faster, or your quenching medium must take heat away quicker than the time required for the carbon change, otherwise the hardening carbon will have changed back again to cement carbon, and you would not change the condition of unhardened steel.

Now, remember we changed as we went up from cement carbon to hardening carbon, and as we went down we changed from hardening carbon back to cement carbon, the condition of soft steel, and what does that teach us? That we must quench above that low condition, otherwise it would change back, and there nature helps us, because it has given us a range of temperature between heating and cooling during which time we have time to go from the fire to the quenching tank without overheating, a condition which would have to take place were the points coincident.

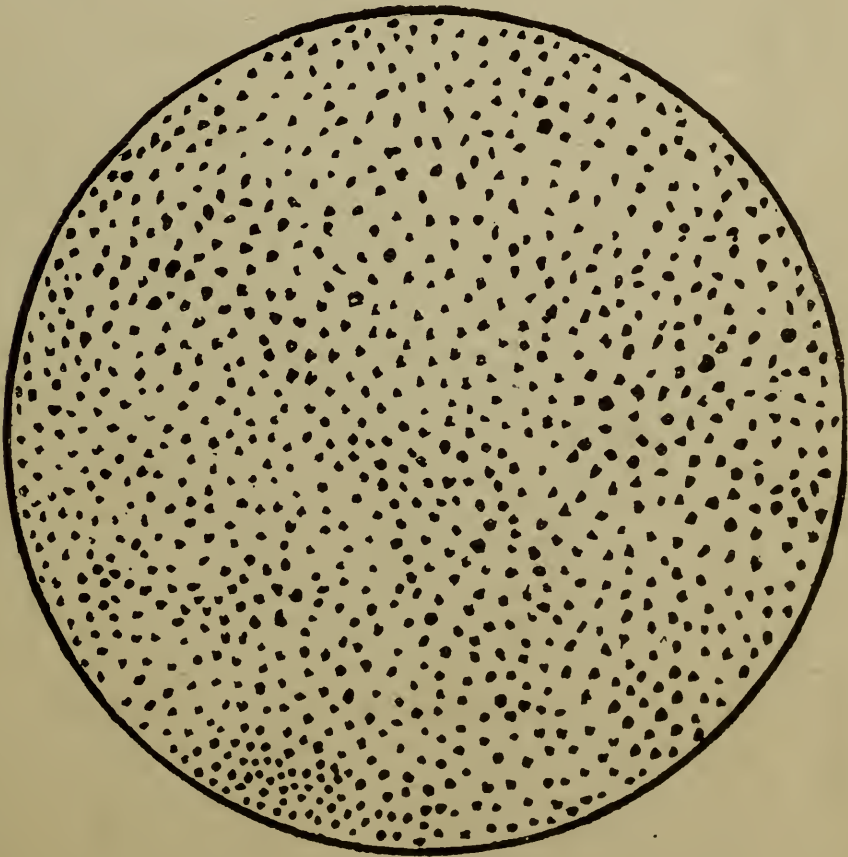If you quench before you get to that change point in

Fig. 9—Martensite

heating up, you get no hardening, because the change has
not taken place, and if you quench after it has gone through
that lower point, you get no hardening either, because the
carbon is again changed from the hardening to the cement
condition.

Martensite, which is a well mixed condition, is shown in
Figure 9 as a conglomerate structure, also has a specific phys-
ical characteristic of its own, from the standpoint of strength.

Martensite is the strongest and is the hardest crystal that
we have in steel. Martensite also has the peculiar property
of being very unstable when it is heated. If we heat mar-
tensite up it tends to go back to a condition of ferrite and
pearlite, and that gives us the rationale for our drawing, or
reheating. You see as we heat up through the change point
and quench we hold the martensite, but as soon as we reheat,
we begin to get martensite of a lower degree, and begin to
introduce some pearlite and some ferrite. After we get high
enough, we find that we have destroyed all our martensite, and
we have gone back to the condition of pearlite and ferrite.

Let us now consider what has happened and what we
have accomplished in heating, to just beyond the change
point and quenching and then reheating. If you will refer
to the various illustrations in which is shown ferrite and
pearlite and even cementite, you will notice that there is no
definite regularity with which the distribution of grains occur.
You notice a number of ferrite grains grouped together and
a number of pearlite grains also grouped together. Also the
condition may be such that the grains are large sized. Now,
each grain has a definite physical characteristic of its own.
One is strong and hard and brittle and another is tough, duc-
tile and comparatively weak. Also the small sized crystals
represent the best physical condition that the particular grain
can be in.

Martensite, as I stated before, represents the best mixed
condition of all of the crystals, and if quenched from a tem-
perature close to the change point, it is fine grained. If we
reheat to any point up to the upper change point, we do not
destroy the well mixed condition, but retain that, and bring

about a physical condition which represents the resultant of the specific physical conditions of the specific grains. The higher we reheat, the more pearlite and ferrite we return to the structure and the more of their physical condition we impart, namely, toughness, ductility and softness. Without hardening and tempering and annealing we have areas having the physical properties of one grain and other areas having the physical properties of a different grain, but the heat treatment gives us the combination of both throughout the mass of the steel.

To illustrate, we can take as an example the making of concrete. If we make a mixture of sand, cement, and of crushed stone and we do not mix it well, we can make a concrete wall; but if we mix it well we can make a concrete wall which is a good deal stronger than one that was not mixed well. In each instance we get the advantage of cement, of sand and of stone, but we get their combined advantages in the best distributed form, and get the stronger and strongest structure.

Now, we have spoken of change points. It will interest many of you how to determine the change point, or in other words, the hardening heat. If you have a pyrometer, that is, a thermometer that will measure high heats (pyrometer simply means "fire measure"), it is no particular trick to get it, because all you have to do is to make a record of temperature and time of heating, and the change points are readily observed. Then you can duplicate those temperatures in your forge.

If you have to depend upon your eye, the following methods will give the change point and the heat is duplicated by color.

For instance: You take a bar of steel and nick it in a half a dozen places to make breaking easier, as you will have to judge by fractures. Put one end in the fire and get that running towards a white heat condition, let the heat travel on out by conduction to a dull red and then quench it in water. Now break the piece at each nicked place and that fracture which is closest and finest grained was nearest to or at the change point.

Now, of course, we are going to have steel, especially that in the lower carbons which will not show such a great difference in fracture with a slight difference in temperature, and in that case we can use another rough method. You know that if we take an ordinary compass, magnetic needle compass, showing north and south, and hold over it a piece of steel, that we can move that needle by the magnetic attraction. We also know that at the change point steel loses its ability to attract a magnet; in other words, it becomes non-magnetic. When it goes through the change point in cooling, it begins to attract the magnet again. We can use that principle as follows:

Lay a compass on a wooden bench, take your sample which is going to be your guide piece, hold it in the fire until it is red hot, take it out and wiggle it over the compass, and if the compass needle moves you are not high enough. Put it back again, heat it some more and repeat until you get a condition where you cannot attract that needle any more, and then quench it. You find you have your material in the best condition as far as the grain is concerned. To duplicate the results, the color of the temperature will have to be remembered. Also you will need a brass tong for the test piece— iron tongs will cause the needle to move.

As to the drawing methods, of course, you are all familiar with the method of taking your lathe tool or chisel, heating it up to full redness, quenching the point and then with a brush scratch the end of it until it is brightened and let the heat run until you get the proper color, and then quench again.

Of course, the quenching does not impart any hardness or any toughness. All the quenching does under that condition is to stop the running of the heat, because if you do not quench and the other end is hot enough, it might cause too much drawing.

I want to again emphasize that quenching below the change point does not effect hardness. It may, however, give cracking troubles. I much prefer an oil bath than color drawing. You can get in an oil tempering bath any condition you

can get with the other method and with a great deal more accuracy. You do not run your heat over the blues. The bluest blues are something like 500 degrees Fahrenheit, which is below the flash point of tempering oil.

There are many hand books which give color equivalents in temperature. Take an iron pot and put oil in it, put your piece in, take a thermometer that will register up to 650 degrees and heat up until the temperature you are trying to obtain is registered on the thermometer, and then take it out and quench it or cool slowly. For temperatures above the flash point of oil, tempering can be done in melted lead and you can get a thermometer to read up to 1,000 degrees Fahrenheit.

The next step in connection with drawing is annealing. Annealling really means the full conversion by heat of the martensite to the original grain condition, but in the intimately mixed condition as spoken of in the concrete wall illustration.

As to just what treatment you want in the particular piece, that depends, of course, upon the material, and also the use to which it is put.

If you desire machining qualities only and intend to heat, treat after machining, heating to full redness and allowing to cool slowly is all that is necessary. If no treatment is given after machining, heating to the change point, and in general for soft steels, to full redness and quenching in water and then reheating will put the steel in good condition.

As to the reheating—the amount all depends upon the hardness you can stand. If wanted very soft, a full red heat is necessary with slow cooling. A little more hardness and a good deal of toughness is obtained by reheating to a low red heat and then quenching or allowing to cool slowly. I prefer water quenching after the reheat, as it is a time and floor space saver. I have also noted that in ordinary forgings this second method of reheating, although making a greater apparent hardness than the unheat treated forgings, gives a freer machining piece and one uniformly hard, so that there is no chatter, especially in lathe operations.

I always prefer water quenching to oil quenching if the

shape of the piece will stand it without cracking. It is cleaner and cheaper and you don't have to bother about keeping the bath cool.

I have here a number of samples, all of which have been given a simple treatment which I will describe later on. These three screws were all made from ordinary cold rolled screw stock. The one not heat treated shows its brittleness. The other two are bent—one is nicked, the other is not—you will note the toughness.

This is a piece of screw stock. One end heat treated, the other is not. You will note how apparently brittle the unheated end is. This forging is of 25 carbon open hearth steel. There was no great difficulty in breaking it, while the other forging after the heat treatment, was nicked and bent, but did not crack. This piece of steel is from a bar of 50 carbon open hearth. Note the two ends. The one which is broken and looks brittle was not heat treated. The bent end had the same heat treatment as the other specimens. A glance at it will show how tough it is. This piece of material with the treatment will make a fine spindle for a lathe or any place where a tough stiff shaft is wanted. This treatment can be given to all forgings up to 50 carbon steel—spindle stock, screw stock and the like—before machining without destroying the free machining qualities. It is advisable, however, in making a large number of pieces from screw stock, and especially where the parts are small, to give the treatment to the piece rather than bar, because I imagine you would not have furnace facilities for treating a long bar.

I also find that chrome nickel and vanadium steel forgings can be given this treatment before machining, without making machining unusually difficult; in fact, in view of the straightening and cleaning necessary after heat treatment, it is better to treat before machining, even with these alloys.

(Mr. Newman here exhibited several samples of forging to the audience.)

The heat treatment is as follows:

Heat to full redness and quench in water. Then heat again to what is called a black heat—nascent red—the red

that you can just see in the dark corner of a blacksmith shop, and quench again. If you are bothered with hardness in machining, you can heat a little hotter on the reheat, but my advice is to hold that heat as low as you can and get free machining. This is a universally good treatment for structural steel, and one that is very simple. Of course, there is a limit to the size of piece which will give good results under heat treatment, or rather as good results as in a smaller section. The limit, of course, depends upon whether we can cool quicker than the time required for hardening carbon to change back to cement carbon. In any event, however, the piece will be improved, whether one inch thick or four inches in diameter.

One more word in regard to hardening carbon tool steels. If you find that after water quenching from the change point you do not get the hardness you want, don't make the mistake of increasing your heat. If you can't get the hardness in water, the chances are that the piece was of large section, and the inside still hot had a drawing tendency on the outside parts, making it softer than you wanted, but increased its toughness. In this case you had better consult a good steel man and get the material that will harden.

You will also understand from what has been said that all steels will harden in water, but the kind of steel and the shape of the piece may require a slower cooling medium to prevent cracking.

We know now what heat treatment can do. The natural question is, why is heat treating necessary? In other words, what brings about the original hardness, what brings about the original brittleness in steel as we get in forgings and bars? I said to you before that high temperature induces large crystals, and large crystals represent brittleness. If you consider that the steel as we get it was poured from the highest temperature that we will ever put into steel; add to that cooling probably slowly (which induces the growth of crystals), and you will appreciate that we have induced into that material the largest possible crystals that we will ever be able to induce. Furthermore, in the rolling operation, and in the hammering operation in the mill, and also in the ham-

mering operation in forge, we have done all of these at a temperature way above the change point. We have not given any heat treatment to cure it, so to speak, consequently we retain the large crystals, the brittle structure that we originally had.

As far as hardness is concerned, you will understand that all steels have more or less an air hardening property—that is, the air cools the red hot piece quicker than the time required to go through the change point, consequently it is not surprising to get bar steel that is hard.

The casting proposition in the mill also suggests the question of the brittleness and heat treating of steel castings. Steel castings are true steel, except that they have not had the structures refined in them through hammering operations, but their brittleness is due to the high temperature from which they were poured. You can convert these castings just the same as you can convert any other steel, by rational heat treatment. Simple annealing will help the castings materially, but for small castings the double heating and quenching treatment is recommended.

Now then, the next step in heating is burned steel. While you can convert overheated steel, you can never convert burned steel, because burned steel has been put into a condition in which the chemical constituents are changed. Something has been burned out of it that has given it life. The condition has been changed, you have an entirely differnet mass, and you can never convert it. The best thing to do is to scrap it.

In regard to the heat treatment of cast iron, that takes in a little bit different explanation than our general mixing theory. If we take white cast iron we find that it is made up of cementite. Cementite, as I said to you, is the highest carbon condition. If that carbide is exposed to high temperature, that is, a temperature above the change point, for any length of time, the tendency is for it to break up, and some of that carbon comes from the cementite and gives us a pure graphite condition. If we allow it to remain at this temperature long enough we get a pearlite condition and a ferrite

condition. This starts from the outside and works in, and we have in good malleable castings—that is, heat treated cast iron—a case made up largely of ferrite, the grain of wrought iron in which are globules of graphite, but the structure as a whole tends to the characteristics of the ferrite and possibly ferrite and pearlite grains.

Now, we can have exactly the same condition as far as chemical structure is concerned in a brittle gray iron as we have in the shell of a malleable casting. We will then have the grain make up; that is, we can have the same amount of ferrite and pearlite and under these conditions graphite.
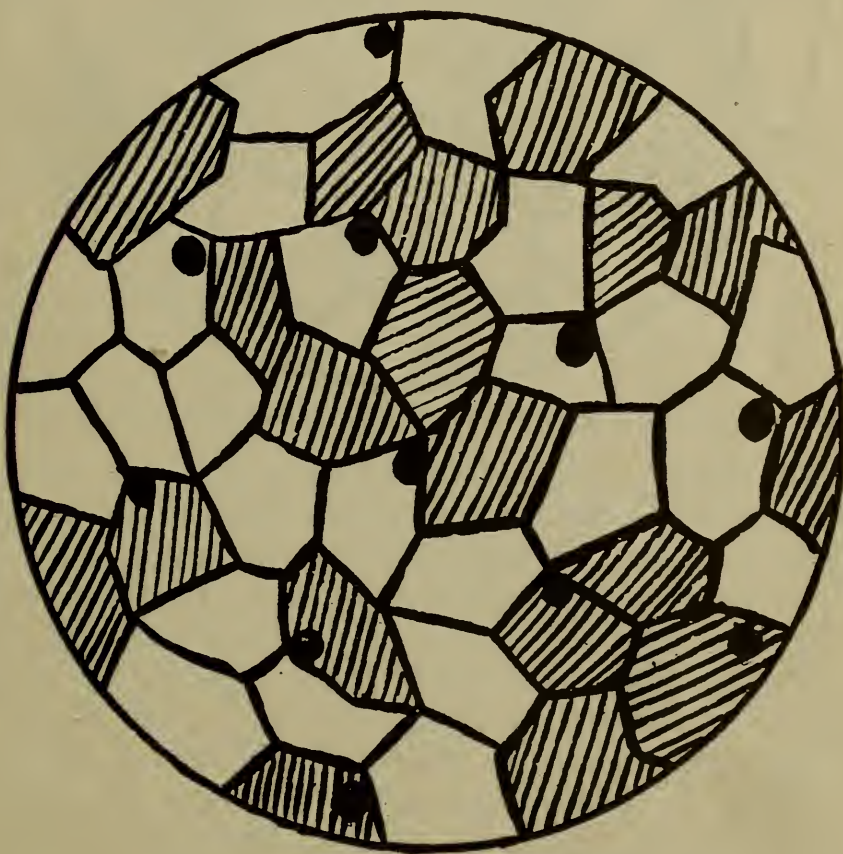

Fig. 10—Malleable Casting Shell, Ferrite-White. Pearlite-Black, Graphite-Black Spots

In the case of a malleable casting we have ductility and malleability, and the gray iron casting is very brittle. The microscope has shown us that the difference between the two is only in the arrangement of the graphite. Figures 10 and
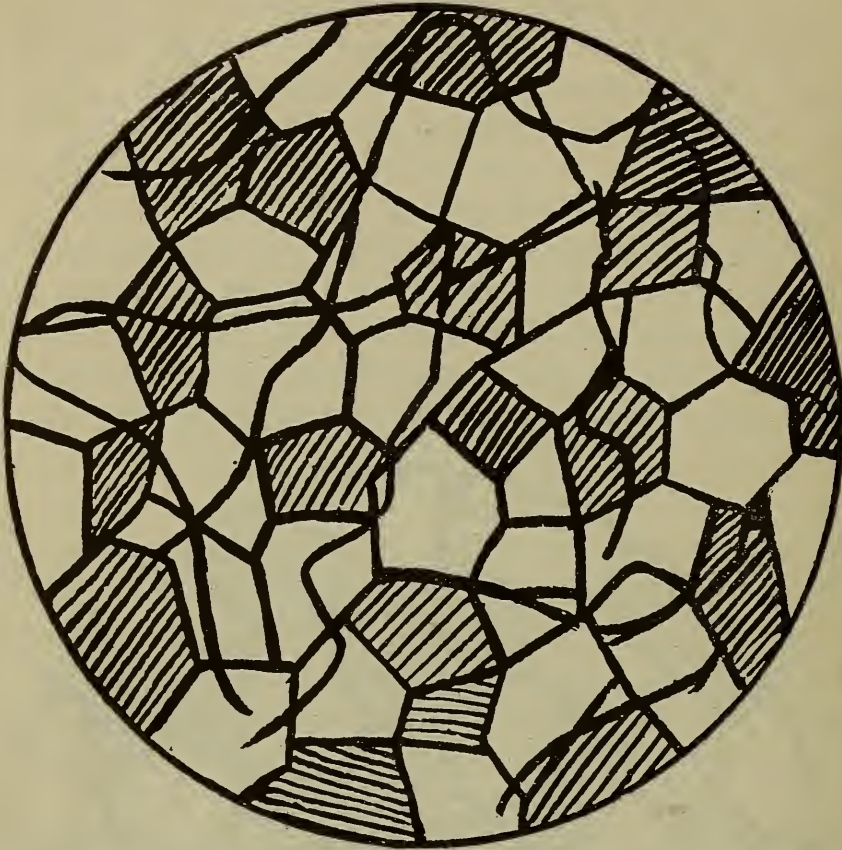
Fig. 11.—Gray Cast Iron, Ferrite-White, Pearlite-Black, Graphite-Lenis

11 are characteristic. Eleven shows a gray iron structure. Throughout the entire mass we have those broad bands, or plates, or ribbons, you might say (they run across and lengthwise), and they break up the entire mass. In a malleabilized casting, or take that portion of the piece which has been truly malleabilized, the graphite has segregated into little circular or globular shapes—in other words, to use common language, the cast iron would be represented as having a whole lot of cracks throughout the mass, microscopic cracks, in which the graphite has been placed, while a malleable casting has a large number of fine microscopic pin holes in which the carbon graphite was placed.

It is only through the difference in the graphite condition that we can really explain the difference between the brittleness of the cast iron and the apparent malleability of the malleable casting. The bands in the cast iron has broken

up the continuity of the mass. You can readily understand the difference between a casting full of cracks and one full of pin holes.

There is one more point, and that is case hardening. When we case harden we are adding a tool steel case to a softer center, in order that we can get the hardness of a tool steel, and also get the toughness and strength of the center of the softer steel. Now, if we heat beyond the change point and expose the steel to a carbon atmosphere—for instance, by packing in bone black or heating in cyanide or any material that will give off carbon at high heat, the carbon will flow in to our steel mass. The longer it is exposed the more carbon is taken up, and the microscope also shows us that the greatest amount of carbon is at the outside of the case, and the lowest amount on the inside; that is, as we increase the depth we also increase the amount of carbon on the outside.

Let us see what takes place. As we increase carbon we decrease the temperature or location of the change point, so that after adding a tool steel case we have a mass which has a lower change point on the outside than on the inside. We have, however, heated to the change point of inside to cause it to take up carbon. We also know that to get quick casing a still higher temperature is necessary, and it is customary to perform the casing operation at a temperature considerably above that of the change point. Now, after casing, if we quenched, you can readily appreciate that the case would not be in its finest grained condition, and if the temperature were high, even the core might be very brittle. It is possible by several quenches to properly adjust the quenching temperatures, so that a hard and fine grained shell can be obtained with a tough and comparatively soft core, which really accomplishes the object of the case hardening operation.

To get good hardening it is necessary to cool slowly after the casing operation.

If you reheat to a temperature between that of the change point of the case and the core and quench you can get very good results. The best results combining toughness

and hardness, however, require two quenches. After the slow cooling from the casing fire, reheat to the change point of the core and quench. Then reheat to the change point of the case and quench again. The first quench refines the core and the second refines the case and anneals the core. To put it into language referring to grain structure, the first quench gives martensite throughout the mass—fine grained on the inside and coarse on the outside. The second reheat changes the inside to pearlite and ferrite and the quench has no effect since the inside was below the change point, but the outside has had fine grained martensite fixed throughout by the quenching operation.

I have here three specimens of case hardening. I will pass them around. All three were heated in a casing box at full red heat for several hours. The material is 25 carbon open hearth. One sample was quenched directly after casing, the other two were slowly cooled. This one sample shows no definite structure between the core and case and the break shows it brittle (referring to the one quenched directly).

The next sample was reheated to the change point of the core and quenched and broken. You will note that it is also brittle, but even though the case is not as clearly defined as in the following sample, still the core is finer grained than the first sample. The third piece had the same operation put to it as the second, and in addition was reheated to the change point of the case and quenched. Note that this piece is bent and broken only part through, an indication of its toughness, and at the same time I want you to notice the fine grain of the case and the apparent fibrous structure of core. The exact operation is as follows:

Heated for three hours in cyanide at 900 degrees Centigrade and cooled slowly. Reheated to 800 degrees Centigrade and water quenched, and then reheated to 720 degrees Centigrade and water quenched.

That is all I have to say, gentlemen, but I will be very glad to answer any questions that may occur to you.

I thank you.